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Global Precipitation Measurement – Report 9
Core Coverage Trade Space Analysis

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Introduction

This paper summarizes the GPM-Core coverage trade space analysis. The goal of this analysis was to determine the GPM-Core sensitivity to changes in altitude and inclination for the three onboard instruments: the radiometer, the KU band radar and the KA band radar (see Table 1). This study will enable a better choice of the nominal GPM-Core orbit as well as the optimal size of the maintenance box (± 1km, ± 5 km…). For this work, we used two different figures-of-merit: (1) the time required to cover 100% of the ±65° latitude band and (2) the coverage obtained for a given propagation time (7 days and 30 days). The first figure-of-merit is used for the radiometer as it has a sensor cone half-angle between 3 to 5 times bigger than the radars. Thus, we anticipate that for this instrument the period of the orbit (i.e. altitude) will be the main driver and that the 100% coverage value will be reached within less than a week. The second figure-of-merit is used for the radar instruments as they have small sensor cone half-angle and will, in some cases, never reach the 100% coverage threshold.

Table 1. GPM-Core Onboard Sensor Properties using a Simple Cone Model (Nadir Pointing).

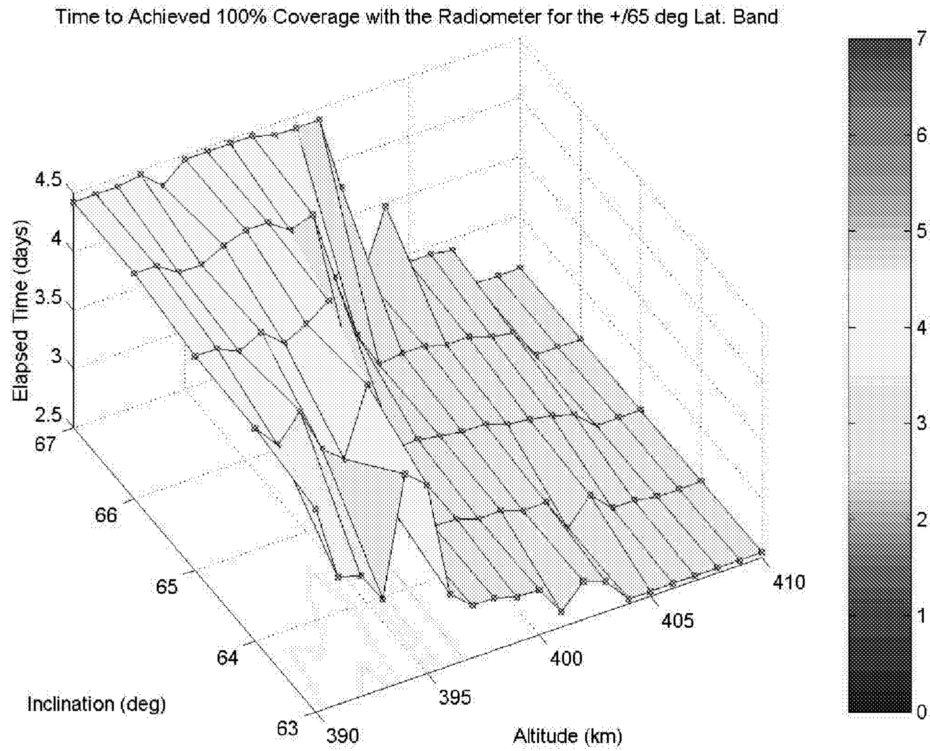
	Radiometer	KU Band Radar	KA Band Radar
Reference Altitude (km)	400	400	400
Swath Width (km)	920	245	125
Half Swath Width (°)	4.1	1.1	0.6
Half-Cone Angle (°)	48	17	9

Using FreeFlyer, we varied the GPM-Core's altitude from 390 to 410 km in steps of 1 km and the inclination from 63 to 67° in steps of 1°. The initial spacecraft Keplerian state is shown in Table 2. For each run, the spacecraft was stepped and the sensor coverage as a function of the elapsed time was recorded. The propagation step size was set to 60 seconds for the radiometer and 10 seconds for both radars so that the sensors' swaths were continuous. The propagation was stopped when the maximum coverage value (100% of the ±65° latitude band) or the maximum propagation time (30 days) was reached. The force model was limited to J_2 only. The coverage was restricted to the ±65° latitude band which translates to a uniform distribution of 4566 points with an area of about 420 km x 420 km/point.

Table 2. GPM-Core Initial Keplerian State.

	GPM-Core
Epoch (UTC)	Jun 1 2001 00:00:00.000
Semimajor axis (km)	*varied*
Eccentricity	0.0001
Inclination (°)	*varied*
Ω(°)	70
ω(°)	0
θ(°)	0

Radiometer Results



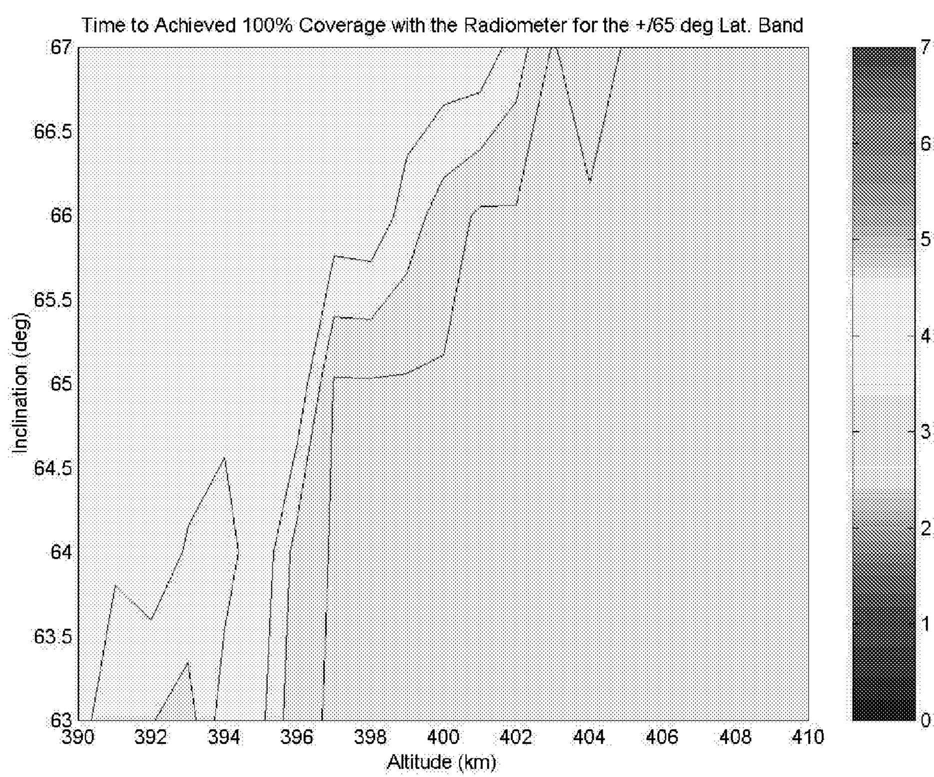
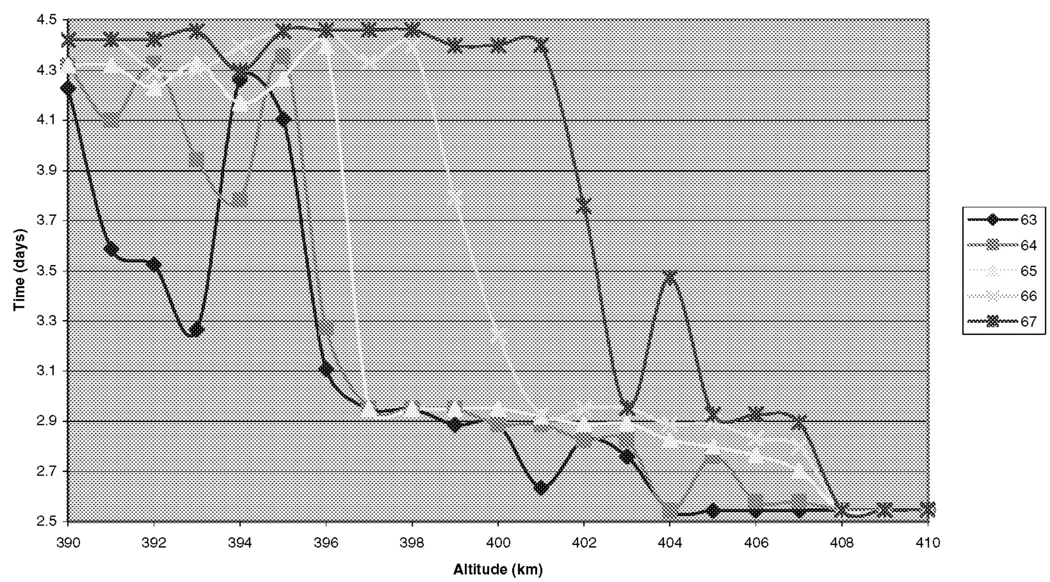


Table 3. Radiometer Required Time to Achieved 100% Coverage vs. GPM-Core Altitude (km) and Inclination(°).

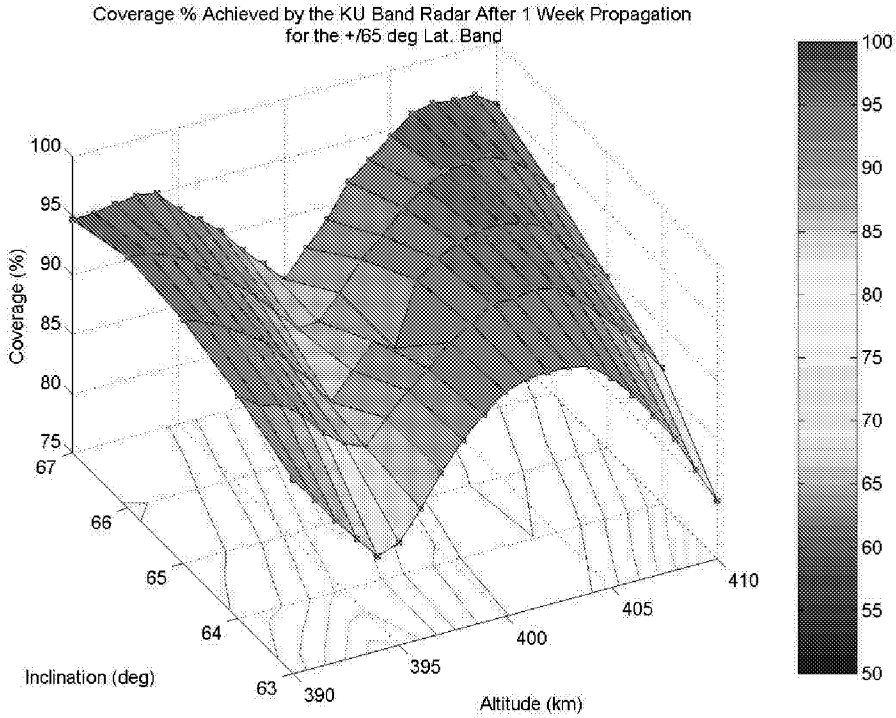
	Inclination(°)				
Altitude (km)	63	64	65	66	67
390	4.227083	4.318056	4.31875	4.420833	4.420833
391	3.5875	4.100694	4.319444	4.421528	4.421528
392	3.524306	4.325694	4.229167	4.294444	4.422917
393	3.265972	3.941667	4.326389	4.295139	4.455556
394	**4.263194**	3.783333	4.167361	4.392361	4.296528
395	4.103472	**4.355556**	4.264583	4.457639	4.457639
396	3.107639	3.273611	**4.394444**	**4.458333**	4.458333
397	2.948611	2.948611	2.949306	4.33125	4.459722
398	2.949306	2.949306	2.95	4.396528	**4.460417**
399	2.885417	2.95	2.95	3.7875	4.397222
400	2.886111	2.886806	2.950694	3.243056	4.398611
401	2.634028	2.8875	2.91875	2.922917	4.399306
402	2.823611	2.823611	2.888194	2.951389	3.758333
403	2.759722	2.824306	2.891667	2.952083	2.952083
404	2.542361	2.543056	2.825	2.8875	3.470833
405	2.543056	2.761111	2.797222	2.893056	2.925694
406	2.54375	2.579861	2.761806	2.829861	2.926389
407	2.544444	2.579861	2.701389	2.797917	2.895139
408	2.545139	2.545139	2.545833	2.545833	2.546528
409	2.545833	2.545833	2.545833	2.546528	2.546528
410	2.546528	2.546528	2.547222	2.547222	2.547917

The numbers in bold represent the maximum value for a given column and the numbers highlighted in gray the minimum value. The light green shaded area highlights the optimal altitude range (within 10 % of the minimum time) for a given column.

Time for the Radiometer to Cover 100% of the +/- 65 deg. Lat. Band.



Ku Band Radar Results



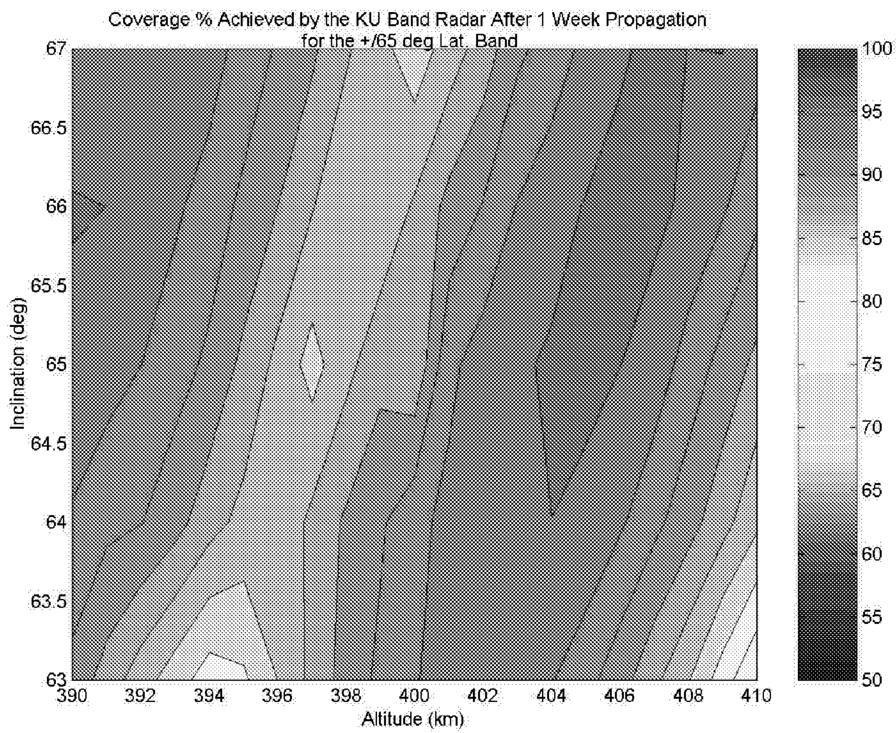
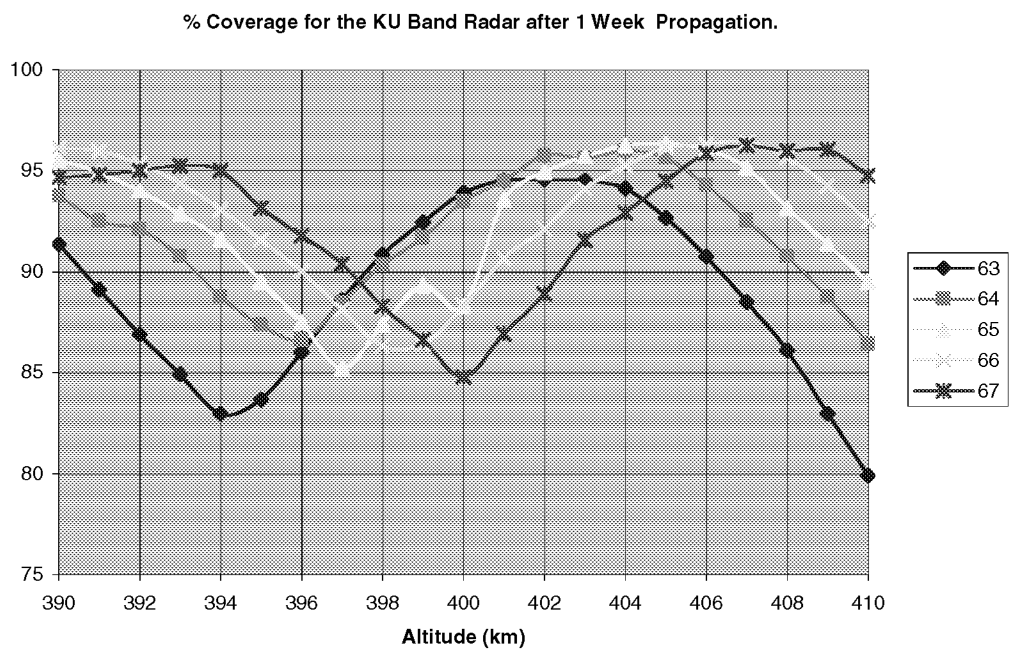


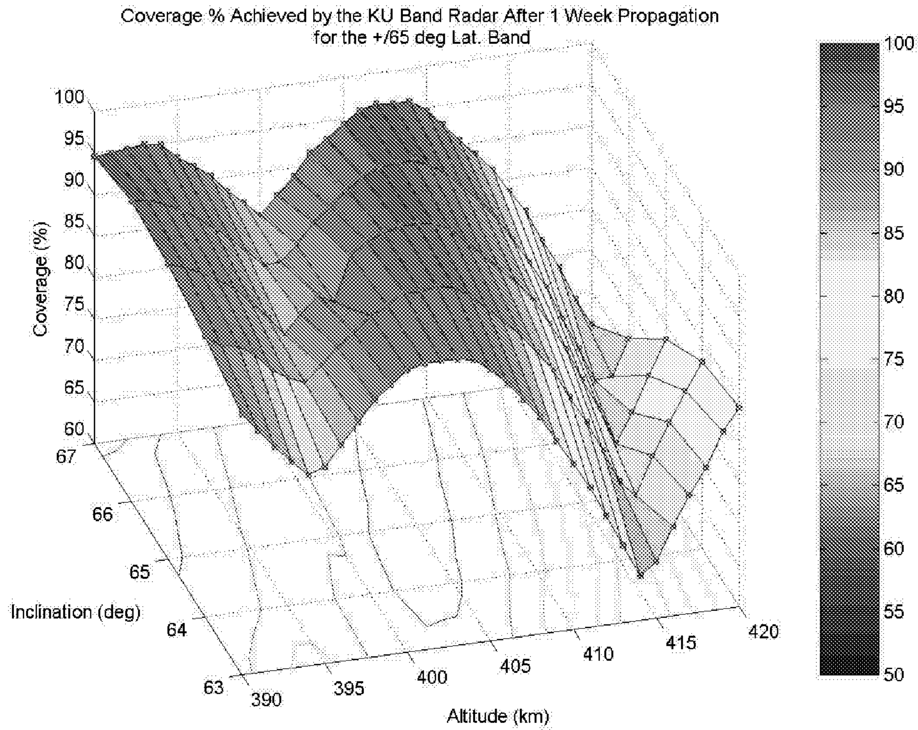
Table 4. KU Band Radar Coverage (%) vs. GPM-Core Inclination (°) and Altitude (km). (7 days)

	Inclination(°)				
Altitude (km)	63	64	65	66	67
390	91.371	93.75821	95.53219	96.14542	94.67806
391	89.1152	92.53176	94.91897	95.99212	94.80946
392	86.9032	92.09374	94.02102	95.35699	95.00657
393	84.91021	90.75777	92.83837	94.37144	95.24748
394	82.98292	88.74288	91.61191	93.05738	95.00657
395	83.66185	87.38502	89.50942	91.56811	93.14498
396	86.00526	86.61848	87.49452	90.01314	91.78712
397	88.58958	88.48007	85.21682	88.15155	90.38546
398	90.84538	90.34166	87.38502	86.31187	88.28296
399	92.46605	91.69952	89.33421	86.39947	86.61848
400	93.91152	93.4954	88.28296	88.28296	84.8007
401	94.52475	94.50285	93.5392	90.67017	86.9251
402	**94.56855**	95.77311	94.91897	92.11564	88.89619
403	94.52475	95.6198	95.7074	94.08673	91.56811
404	94.13053	**95.99212**	96.25493	95.26938	92.90407
405	92.68506	95.6417	**96.36443**	96.12352	94.48095
406	90.75777	94.28384	96.03592	96.32063	95.86071
407	88.50197	92.55366	95.15988	**96.45204**	**96.25493**
408	86.11476	90.75777	93.16689	95.6417	95.99212
409	82.98292	88.74288	91.3491	94.26194	96.05782
410	79.89488	86.42138	89.46562	92.48795	94.76566

The numbers in bold represent the maximum value for a given column and the numbers highlighted in gray the minimum value. The light green shaded area highlights the optimal altitude range (within 0.5 % of the maximum coverage) for a given column.



Additional Runs (KU Band - 1 Week Propagation)



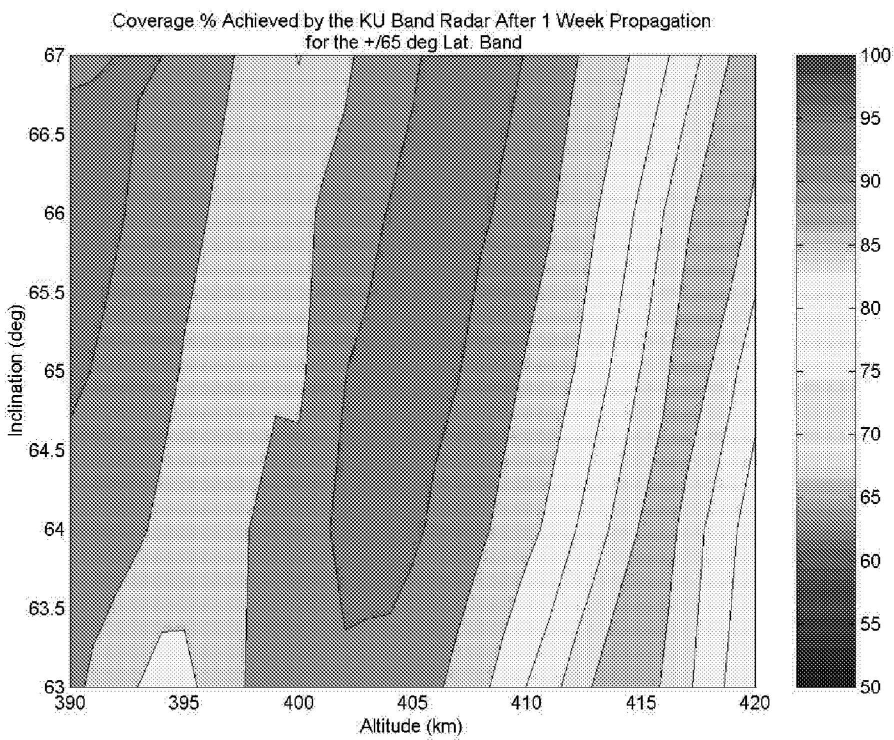
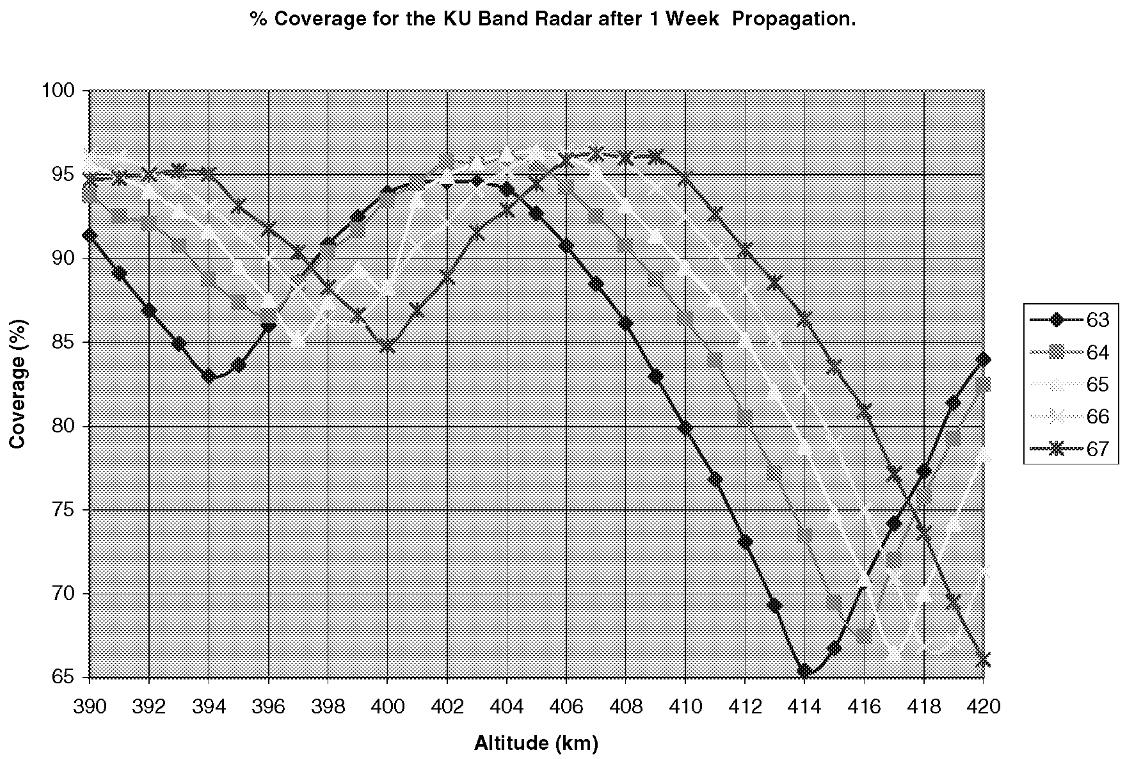
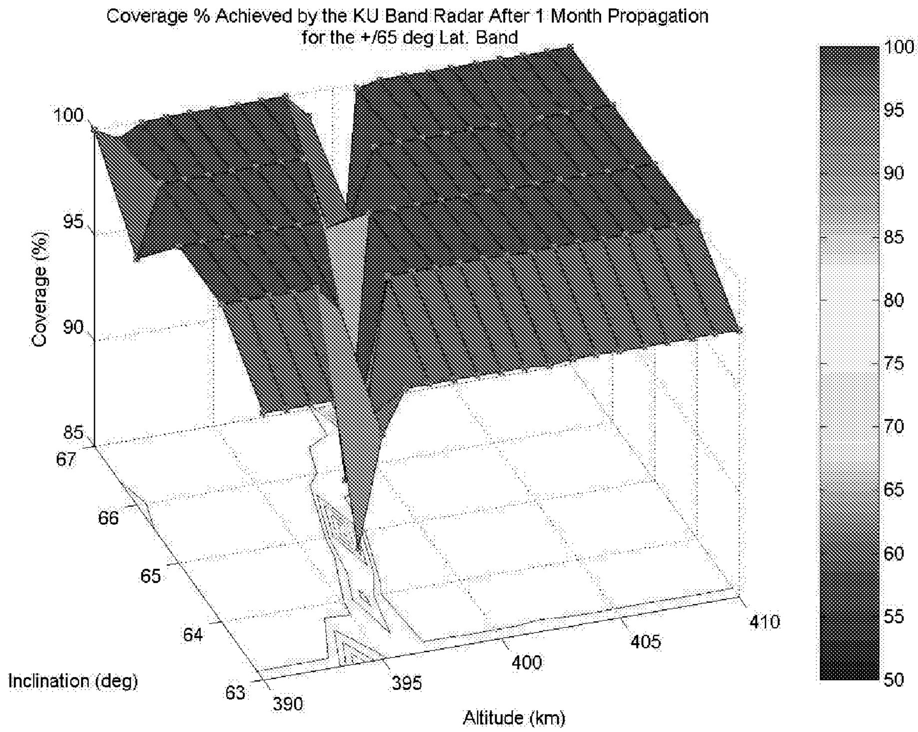


Table 5. KU Band Radar Coverage (%) vs. GPM-Core Inclination (°) and Altitude (km). (7 days).
Additional Runs

	Inclination(°)				
Altitude (km)	63	64	65	66	67
390	91.371	93.75821	95.53219	96.14542	94.67806
391	89.1152	92.53176	94.91897	95.99212	94.80946
392	86.9032	92.09374	94.02102	95.35699	95.00657
393	84.91021	90.75777	92.83837	94.37144	95.24748
394	82.98292	88.74288	91.61191	93.05738	95.00657
395	83.66185	87.38502	89.50942	91.56811	93.14498
396	86.00526	86.61848	87.49452	90.01314	91.78712
397	88.58958	88.48007	85.21682	88.15155	90.38546
398	90.84538	90.34166	87.38502	86.31187	88.28296
399	92.46605	91.69952	89.33421	86.39947	86.61848
400	93.91152	93.4954	88.28296	88.28296	84.8007
401	94.52475	94.50285	93.5392	90.67017	86.9251
402	**94.56855**	95.77311	94.91897	92.11564	88.89619
403	94.52475	95.6198	95.7074	94.08673	91.56811
404	94.13053	**95.99212**	96.25493	95.26938	92.90407
405	92.68506	95.6417	**96.36443**	96.12352	94.48095
406	90.75777	94.28384	96.03592	96.32063	95.86071
407	88.50197	92.55366	95.15988	**96.45204**	**96.25493**
408	86.11476	90.75777	93.16689	95.6417	95.99212
409	82.98292	88.74288	91.3491	94.26194	96.05782
410	79.89488	86.42138	89.46562	92.48795	94.76566
411	76.82873	83.94656	87.56023	90.47306	92.66316
412	73.10556	80.5081	85.15112	88.12965	90.51686
413	69.29479	77.20105	82.04117	85.23872	88.56767
414	65.39641	73.47788	78.77792	82.26018	86.42138
415	66.75427	69.44809	74.79194	78.97503	83.55234
416	70.69645	67.477	70.91546	74.94525	80.90232
417	74.17871	72.01051	66.46956	70.93736	77.13535
418	77.33246	75.84319	69.99562	66.84187	73.60929
419	81.38414	79.28165	74.17871	67.12659	69.4919
420	83.99036	82.47919	78.2961	71.37538	66.05344

The numbers in bold represent the maximum value for a given column and the numbers highlighted in gray the minimum value.
The light green shaded area highlights the optimal altitude range (within 0.5 % of the maximum coverage) for a given column.


% Coverage for the KU Band Radar after 1 Week Propagation.
100
95
90
85
80
75
70
65
Coverage (%)
390
392
394
396
398
400
402
404
406
408
410
412
414
416
418
420
Altitude (km)
63
64
65
66
67


Coverage % Achieved by the KU Band Radar After 1 Month Propagation
for the +/65 deg Lat. Band
Coverage (%)
100
95
90
85
67
66
65
64
63
Inclination (deg)
390
395
400
405
410
Altitude (km)
100
95
90
85
80
75
70
65
60
55
50

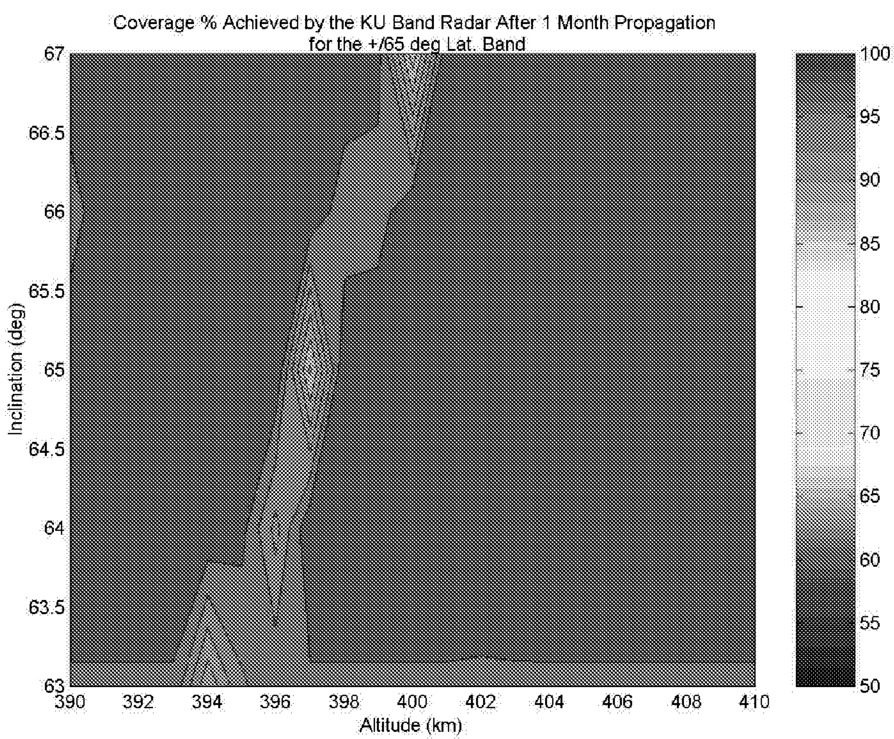
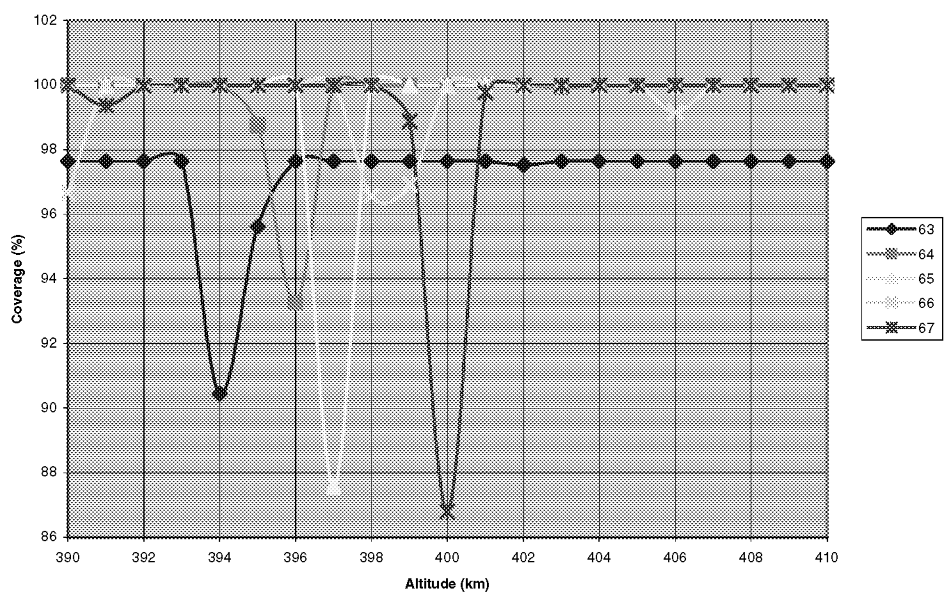

Coverage % Achieved by the KU Band Radar After 1 Month Propagation
for the +/65 deg Lat. Band
Inclination (deg)
67
66.5
66
65.5
65
64.5
64
63.5
63
390
392
394
396
398
400
402
404
406
408
410
Altitude (km)
100
95
90
85
80
75
70
65
60
55
50

Table 6. KU Band Radar Coverage (%) vs. GPM-Core Inclination (°) and Altitude (km). (30 days)

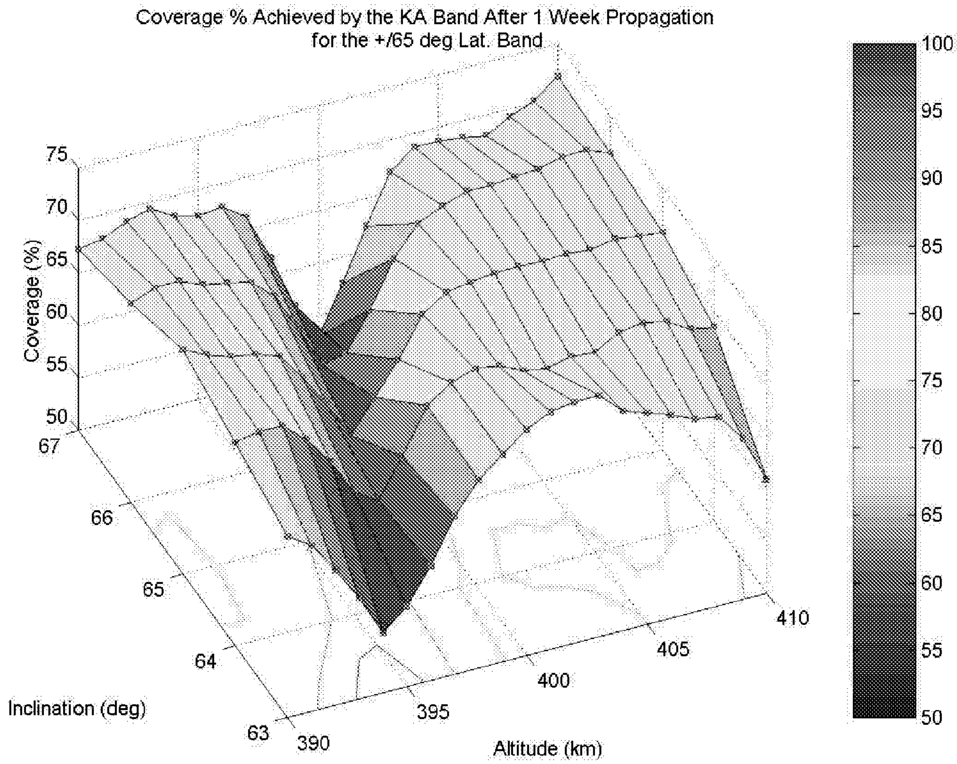
	Inclination(°)				
Altitude (km)	63	64	65	66	67
390	**97.6346912**	**100**	**100**	96.64915	**100**
391	**97.6346912**	**100**	**100**	**100**	99.36487
392	**97.6346912**	**100**	**100**	**100**	99.9781
393	**97.6346912**	**100**	**100**	**100**	**100**
394	90.45116075	**100**	**100**	**100**	**100**
395	95.61979851	98.75164	**100**	**100**	**100**
396	**97.6346912**	93.25449	**100**	**100**	**100**
397	**97.6346912**	**100**	87.56023	**100**	**100**
398	**97.6346912**	**100**	**100**	96.56154	**100**
399	**97.6346912**	**100**	**100**	96.91196	98.88305
400	**97.6346912**	**100**	**100**	**100**	86.79369
401	**97.6346912**	**100**	**100**	**100**	99.78099
402	97.52518616	**100**	**100**	**100**	**100**
403	**97.6346912**	99.9124	**100**	**100**	**100**
404	**97.6346912**	**100**	**100**	**100**	**100**
405	**97.6346912**	**100**	**100**	**100**	**100**
406	**97.6346912**	**100**	**100**	99.14586	**100**
407	**97.6346912**	**100**	**100**	**100**	**100**
408	**97.6346912**	**100**	**100**	**100**	**100**
409	**97.6346912**	**100**	**100**	**100**	**100**
410	**97.6346912**	**100**	**100**	**100**	**100**

The numbers in bold represent the maximum value for a given column and the numbers highlighted in gray the minimum value.

% Coverage for the KU Band Radar after 1 Month Propagation.



Ka Band Radar Results



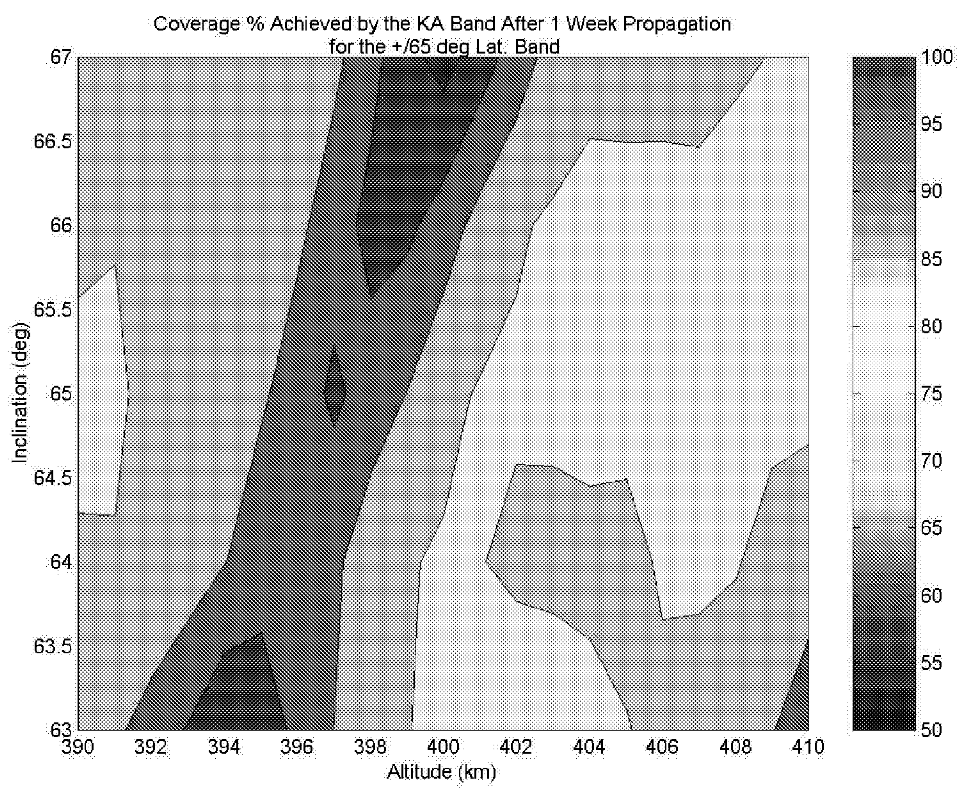
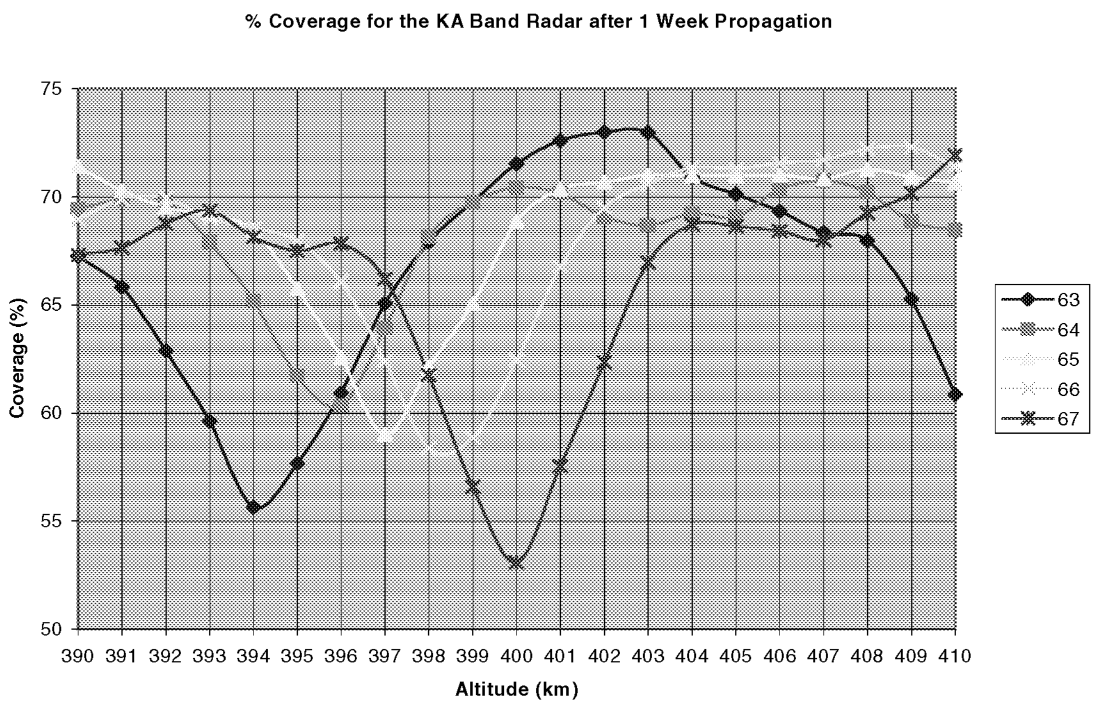
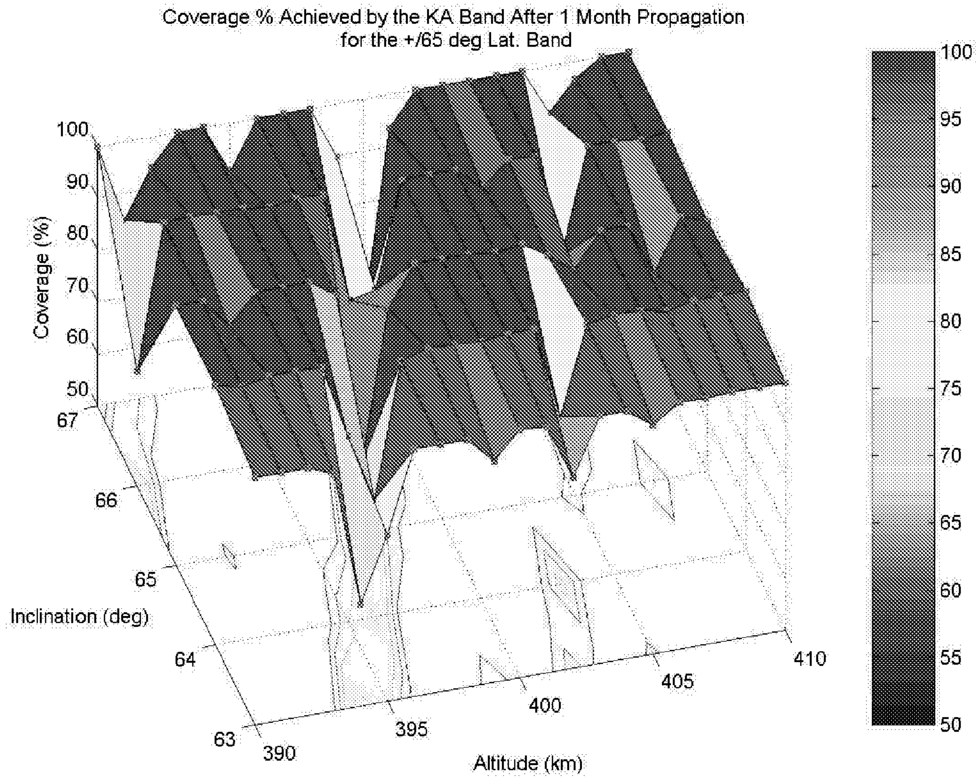


Table 7. Ka Band Radar Coverage (%) vs. GPM-Core Inclination (°) and Altitude (km) for a 7 Days Propagation.

	Inclination(°)				
Altitude (km)	63	64	65	66	67
390	67.25799	69.42619	71.39728	68.94437	67.3237
391	65.83443	69.88611	70.30223	69.90802	67.65221
392	62.87779	69.82041	69.5138	69.92992	68.76916
393	59.61454	67.91502	69.18528	68.98817	69.36049
394	55.65046	65.1774	68.44065	68.55015	68.13403
395	57.66535	61.69514	65.74682	67.98073	67.4989
396	60.9286	60.33728	62.57118	66.07534	67.82742
397	65.06789	63.92904	59.00131	62.39597	66.20675
398	67.89312	68.13403	62.13316	58.36618	61.76084
399	69.77661	69.75471	65.06789	58.86991	56.5922
400	71.52869	70.43364	68.85677	62.43977	53.08804
401	72.60184	70.17083	70.36794	66.75427	57.53395
402	**72.99606**	69.07578	70.67455	69.5138	62.35217
403	72.97416	68.68156	71.00307	70.58695	66.97328
404	70.91546	69.22908	70.95926	71.35348	68.72536
405	70.12703	69.07578	70.95926	71.30968	68.63776
406	69.33859	70.34604	71.00307	71.57249	68.41875
407	68.35304	**70.74025**	70.82786	71.7258	68.00263
408	67.98073	70.21463	**71.26588**	72.20762	69.25099
409	65.265	68.85677	70.91546	**72.29523**	70.17083
410	60.8629	68.46255	70.65265	71.39728	**71.92291**

The numbers in bold represent the maximum value for a given column and the numbers highlighted in gray the minimum value. The light green shaded area highlights the optimal altitude range (within 0.5 % of the maximum coverage) for a given column.




Coverage % Achieved by the KA Band After 1 Month Propagation
for the +/65 deg Lat. Band
Coverage (%)
Inclination (deg)
Altitude (km)

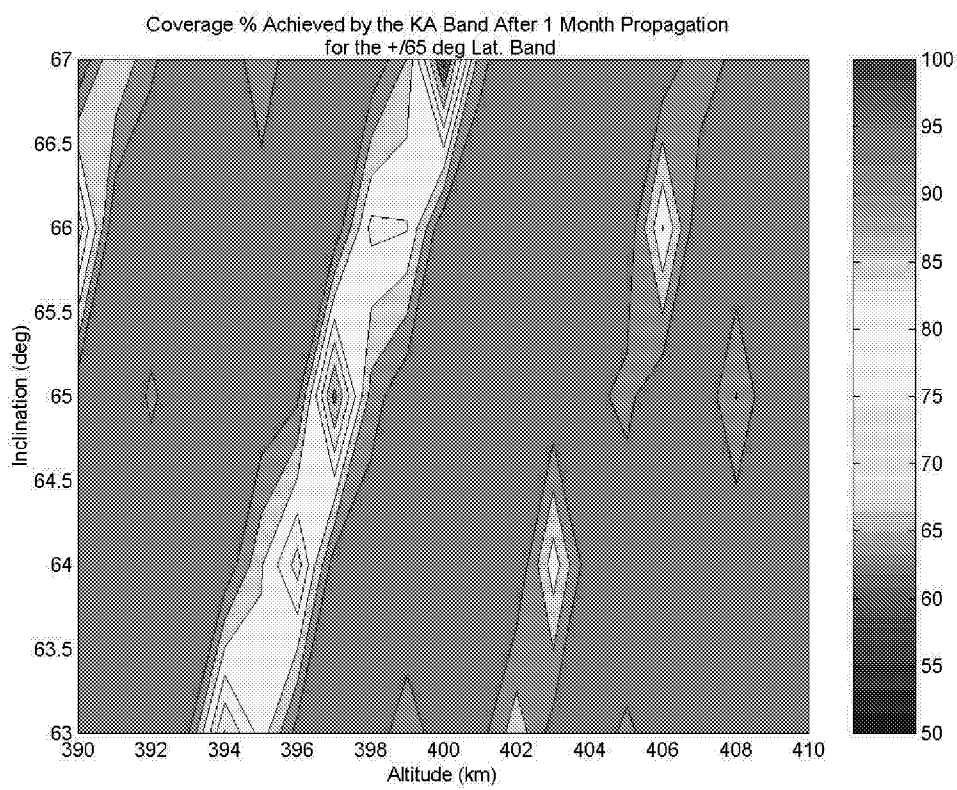
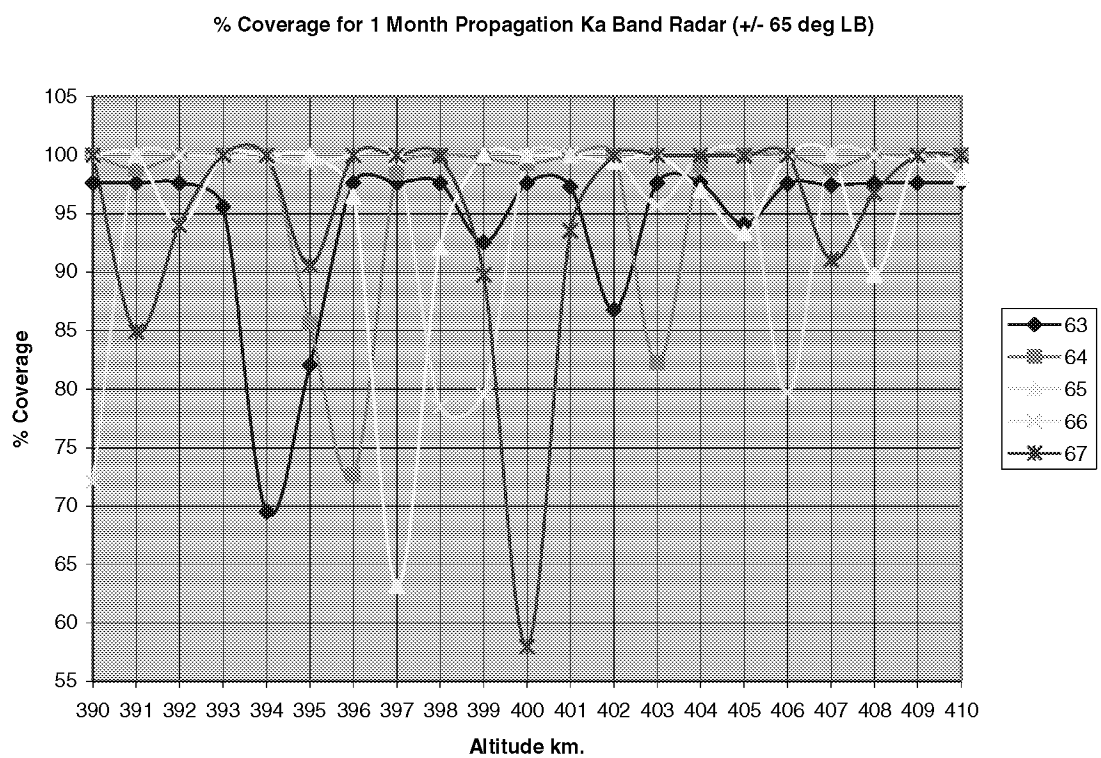

Coverage % Achieved by the KA Band After 1 Month Propagation
for the +/65 deg Lat. Band
Inclination (deg)
Altitude (km)

Table 8. Ka Band Radar Coverage (%) vs. GPM-Core Inclination (°) and Altitude (km) for one Month Propagation.

	Inclination(°)				
Altitude (km)	63	64	65	66	67
390	**97.63469**	**100**	**100**	72.01051	**100**
391	97.61279	98.81735	**100**	99.75909	84.93211
392	**97.63469**	99.9343	94.06483	**100**	94.02102
393	95.576	**100**	**100**	99.89049	**100**
394	69.4919	99.9124	**100**	99.75909	**100**
395	82.04117	85.61104	100	99.14586	90.58257
396	97.61279	72.64564	96.49584	**100**	**100**
397	**97.63469**	98.44503	63.16251	99.71529	**100**
398	**97.63469**	**100**	92.13754	78.49321	99.9343
399	92.55366	99.71529	**100**	79.54446	89.77223
400	**97.63469**	99.29917	**100**	99.86859	57.97197
401	97.30618	99.9343	**100**	**100**	93.5392
402	86.74989	**100**	99.45247	**100**	**100**
403	**97.63469**	82.21638	**100**	95.6855	**100**
404	**97.63469**	99.10206	96.99956	**100**	**100**
405	94.08673	**100**	93.32019	99.89049	99.9343
406	97.59089	**100**	**100**	79.69777	**100**
407	97.41568	98.92685	**100**	**100**	91.06439
408	**97.63469**	**100**	89.77223	**100**	96.73675
409	**97.63469**	**100**	**100**	99.40867	**100**
410	**97.63469**	**100**	98.11651	99.9343	**100**

The numbers in bold represent the maximum value for a given column and the numbers highlighted in gray the minimum value.

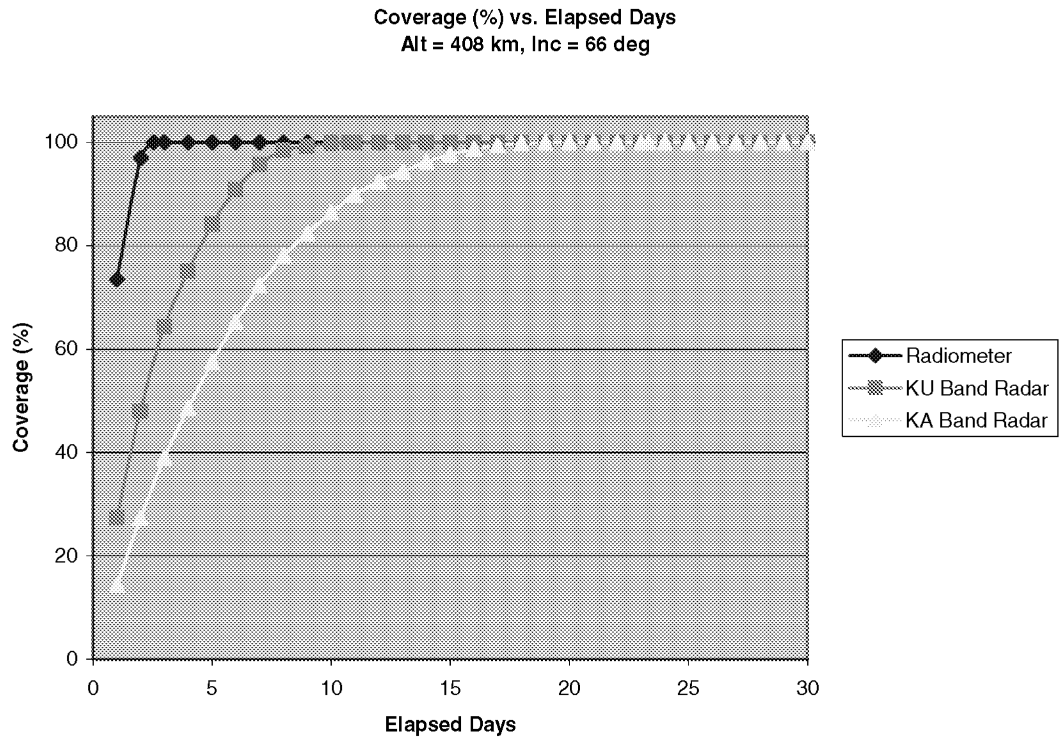


Conclusions

As expected, the radiometer's results are mainly driven by the spacecraft's altitude. Indeed, a higher altitude means a larger sensor swath width. Thus, the spacecraft covers 100% of the specified latitude band faster as the altitude grows. The increase in the spacecraft period due to the increase in altitude has an insignificant effect on the trends mainly because the sensor cone half angle is fairly large. In addition, a lower inclination seems favorable, as the spacecraft sensor's swath will cover more of the area of interest (i.e. the ±65° latitude band). For example, at 65 degrees inclination and 400 km altitude, the radiometer covers a latitude band of ± 69°, the additional 4° corresponding to half of the spacecraft swath width. However, at an inclination of 63 degrees, the latitude band covered is restricted to ± 67°, which represents a higher proportion of the ± 65° latitude band, thus lowering the required coverage time. Both the Ku Band and Ka Band Radars (for the 7 days and 30 days propagation) exhibit distinct zones of poor coverage, which are expected to match "repeat cycle" or near-"repeat cycle" orbits. For a repeat cycle orbit, the spacecraft's ground track repeats itself after *n* revolutions around the Earth, thus leaving identical uncovered areas every *n* revolutions and limiting the coverage to the value reached for one repeat cycle (for a perfect repeat cycle orbit). For both radars, an inclination of 63 degrees should be avoided as their sensor field-of-view is not wide enough to cover entirely the ± 65° latitude band. For this inclination, both instruments reach a maximum coverage of about 97% after 30 days. Table 9 summarizes the optimal altitude range and its average figure-of-merit values for a given inclination for each instrument. The optimal altitude range is determined by including any altitude within 0.5% (absolute margin) of the maximum coverage for the radars data or any altitude within 10% (relative margin) of the minimum time for the radiometer data. A nominal orbit with an inclination of 66 degrees and an altitude of 408 km with ± 1 km control box seems a good trade-off between all the instrument performances. For this specific orbit, a plot of each instrument coverage history is provided below.

Table 9. Results Summary: Optimal Alt. Range vs. Inc.
and <u>Suggested</u> Optimal Operational Orbit and Control Box.

	Optimal Altitude Range (km)						
Inclination(°)	*Radiometer*	**Avg. Days**	*Ku Band (7 days)*	**Avg. %**	*Ka Band (7 days)*	**Avg. %**	***Optimal Altitude (± control box)***
63	403-410	**2.571**	401-404	**94.44**	401-403	**72.85**	**404 (± 1 km)**
64	404-410	**2.593**	402-405	**95.75**	406-408	**70.43**	**406 (± 1 km)**
65	405-410	**2.649**	404-406	**96.22**	403-409	**71.00**	**407(± 1 km)**
66	407-410	**2.609**	405-407	**96.30**	407-409	**72.00**	**408(± 1 km)**
67	408-410	**2.547**	406-409	**96.04**	410	**71.92**	**410(± 1 km)**



Coverage (%) vs. Elapsed Days
Alt = 408 km, Inc = 66 deg
Coverage (%)
Elapsed Days
0
20
40
60
80
100
0
5
10
15
20
25
30
Radiometer
KU Band Radar
KA Band Radar

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13. ABSTRACT *(Maximum 200 words)*

This paper summarizes the GPM-Core coverage trade space analysis. The goal of this analysis was to determine the GPM-Core sensitivity to changes in altitude and inclination for the three onboard instruments: the radiometer, the KU band radar and the KA band radar (see Table 1). This study will enable a better choice of the nominal GPM-Core orbit as well as the optimal size of the maintenance box (± 1km, ± 5 km…). For this work, we used two different figures-of-merit: (1) the time required to cover 100% of the ±65° latitude band and (2) the coverage obtained for a given propagation time (7 days and 30 days). The first figure-of-merit is used for the radiometer as it has a sensor cone half-angle between 3 to 5 times bigger than the radars. Thus, we anticipate that for this instrument the period of the orbit (i.e. altitude) will be the main driver and that the 100% coverage value will be reached within less than a week. The second figure-of-merit is used for the radar instruments as they have small sensor cone half-angle and will, in some cases, never reach the 100% coverage threshold point.

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